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Effects of Habitat Disturbance from Residential Development on Breeding Bird Communities in Riparian Corridors

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ABSTRACT / This study assessed the relationship among land use, riparian vegetation, and avian populations at two spatial scales. Our objective was to compare the vegetated habitat in riparian corridors with breeding bird guilds in eight Rhode Island subwatersheds along a range of increasing residential land use. Riparian habitats were characterized with fine-scale techniques (used field transects to measure riparian vegetation structure and plant species richness) at the reach spatial scale, and with coarse-scale landscape techniques (a Geographic Information System to document land-cover attributes) at the subwatershed scale. Bird surveys were conducted in the riparian zone, and the observed bird species were separated into guilds based on tolerance to human disturbance, habitat preference, foraging type, and diet preference. Bird guilds were correlated with riparian vegetation metrics, percent impervious surface, and percent residential land use, revealing patterns of breeding bird distribution. The number of intolerant species predominated below 12% residential development and 3% impervious surface, whereas tolerant species predominated above these levels. Habitat guilds of edge, forest, and wetland bird species correlated with riparian vegetation. This study showed that the application of avian guilds at both stream reach and subwatershed scales offers a comprehensive assessment of effects from disturbed habitat, but that the subwatershed scale is a more efficient method of evaluation for environmental management.

Riparian zones are biologically diverse and structurally complex habitats that support a diversity of bird species and may provide nesting habitat for more species of birds in North America than any other vegetation type (Sanders 1998). As transitional areas between terrestrial and aquatic systems, their degradation or fragmentation affects the quality of both, along with their associated plants and wildlife (Croonquist and Brooks 1991). Disturbances of the riparian corridor, such as from encroaching development, are often reflected in riparian and aquatic fauna. Changes in riparian indicators may precede aquatic indicators because they respond more directly to terrestrial disturbances (Bryce and others 2002).

One such early indicator being used to determine the condition of riparian zones is bird assemblages or guilds (Bryce and others 2002; Brooks and others 1998), because birds are sensitive to land use and habitat alteration (Forman and others 1976). Birds have strong public appeal and meet other important criteria for ecological indicators: survey methods are well established and nondestructive, methods are inexpensive, many trained field observers are available, and long-term databases and ongoing programs exist (O'Connell and others 1998, 2000).

KEY WORDS: Birds; Habitat; Urbanization; Riparian; Watershed assessment; Land use; Monitoring

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Guilds have been defined as ''groups of species that exploit the same class of environmental resources in a similar way'' (Root 1967). Bird guilds were shown to have potential value in environmental assessment and wildlife management, and have been used for this purpose in several regions of the world (Verner 1984). The whole-guild approach, which counts all species in each guild, is a way to monitor trends in habitat capabilities, and by extension, trends in wildlife populations. Verner (1984) recommended using breeding birds for monitoring because he speculated that an environment that could support an assemblage of breeding birds would probably also support transient and winter-resident species. Bird guilds are increasingly being used in various regions of the United States to show effects on species composition from human disturbances such as fragmented forests, agriculture, and urbanization. Easily developed from species lists, guilds can provide insight into functional characteristics of a community. The guild approach in conjunction with landscape patterns may be useful to analyze the functionality, degree of degradation, and restoration possibilities of riparian habitat (Brooks and Croonquist 1990, 1991).

This study focused on the relationship between vegetated riparian habitat and guilds of breeding birds on sites located along a gradient of residential land use (RLU) at two spatial scales, subwatershed and local stream reach. Riparian vegetation provides nesting and foraging habitat for breeding birds (Sanders 1998). To determine the possible effects on this habitat from RLU and to assess its suitability to support breeding birds, we investigated the association of bird guilds based on their preferred vegetation, foraging behavior, diet, and tolerance to humans, with various land uses and vegetated habitat. We wanted to determine which bird guilds were present in the habitat protected by the regulated buffer and to look for thresholds of effects from landscape stressors that would be helpful to environmental managers in protecting riparian vegetated habitat and breeding bird populations.

Our objectives were to (1) assess the quantity and attributes of riparian vegetation across a land use gradient, (2) determine the relationship between bird guilds and a gradient of RLU, and (3) identify thresholds for bird communities and land use.

Methods

Site Descriptions

Eight sampling sites were chosen to represent a range of anthropogenic land use in their surrounding subwatersheds (Figure 1).

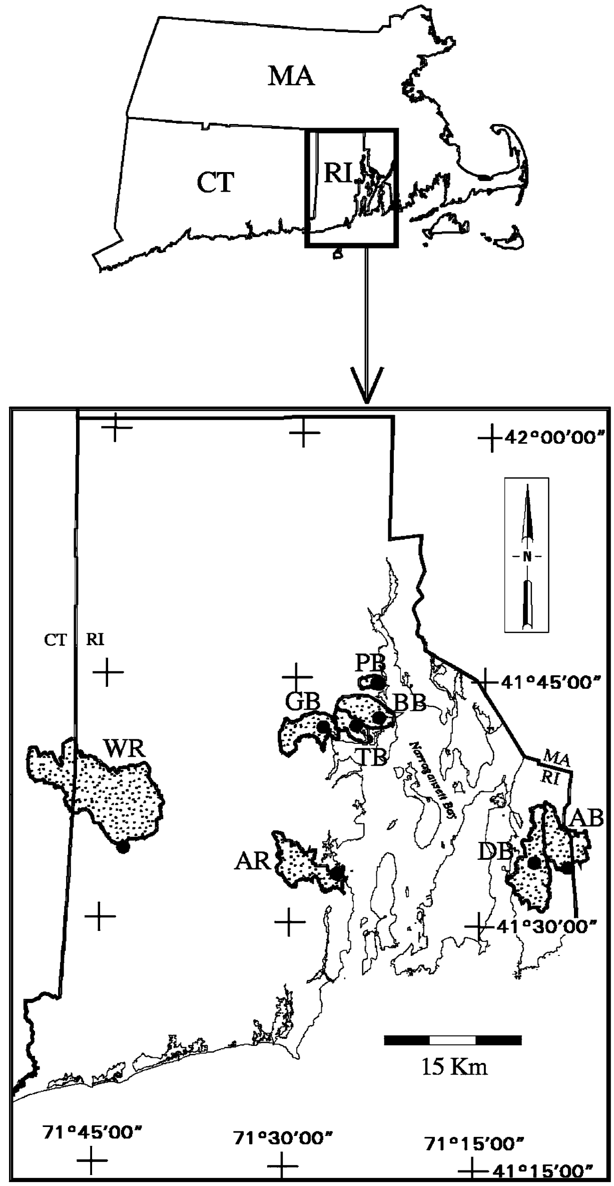

Figure 1. Location of bird survey points in Rhode Island with delineation of subwatersheds: (AB) Adamsville Bk., (AR) Annaquatucket R., (BB) Buckeye Bk., (DB) Donovan Bk., (GB) Gorton Bk., (PB) Passeonkquis Bk., (TB) Tuscatucket Bk., and (WR) Wood R.

Our sites were selected along a gradient of 4–59% RLU. Sites from 4% to 17% RLU included state stream reference sites with less impact from development, sites from 24% to 38% RLU included mixed business and residential use, and sites from 53% to 59% RLU had streams running through or adjacent to densely developed residential areas (Table 1).

The subwatersheds were delineated with 15-minute (1:24,000 scale) topographic maps from the United

Table 1. Physical descriptions of riparian sites ranging from low to high residential land use

Site	Percent residential land use	Site description
Wood River (WR)	4	An inland river in Richmond, RI, off a two-lane highway in a heavily forested watershed-protection area; it serves as the state's principal reference stream.
Adamsville Brook (AB)	12	In Tiverton, RI, on the east side of Narragansett Bay, adjacent to a two-lane highway in a heavily forested area; it serves as the state's reference coastal stream.
Donovan Brook (DB)	17	In Tiverton, RI, on the east side of Narragansett Bay, off a small residential road; it is completely shaded by an extensive wooded riparian zone.
Annaquatucket River (AR)	24	In North Kingstown, RI, in a business/residential area, flows from a pond, under a two-lane road over a fish ladder; the riparian zone is mostly shaded by an extensive wooded area heavily used by fishermen.
Buckeye Brook (BB)	29	In Warwick, RI, in a residential area, riparian zone is well wooded and shades most of the stream.
Gorton Brook (GB)	38	In Warwick, RI, in a mixed commercial/residential area; flows from Gorton Pond, a local swimming area, along a small road adjacent to a commercial development; it is shaded by a wooded riparian zone.
Tuscatucket Brook (TB)	53	In Warwick, RI, in a commercial/residential area adjacent to a four-lane highway; riparian zone consists of a wooded swamp that smells of petroleum; the brook is heavily laden with trash.
Passeonkquis Brook (PB)	59	In Warwick, RI, in the center of a residential area, flows underground, then out from a culvert and runs a short distance through a housing development into a salt marsh; the wooded riparian zone is very narrow, with residences on either side.

States Geological Survey (USGS). Hydrography, digital elevation models (DEMs), and land use and land cover data obtained from the Rhode Island Geographic Information System (RIGIS 1986) were then extracted for each subwatershed using ARC/INFO software (Environmental System Research Institute). The layers for hydrography were derived from 1:24,000-scale USGS topographic maps. The DEMs came from USGS digital elevation models and had a resolution of 30 m. The data layer for land use and land cover (Table 2) was developed from 1995 aerial photography (1:24,000 scale) coded to Anderson modified level 3 to one half acre minimum polygon resolution (Anderson and others 1976).

We characterized the subwatersheds by the relative amounts of natural and human-altered land, which included all land uses, but because we were focusing on urbanization, the sites were characterized by low to high %RLU (Table 3).

We conducted the vegetation and breeding-bird surveys in riparian corridors along 100-m stream reaches, all of which were located just above coastal salt marshes except for the Wood River, which was included as a reference site (from the state of Rhode Island wadeable stream survey). We walked each 100-m stream reach with a tape measure and marked the 0 and 100-m points. Stream riparian zones were defined as intact vegetated corridors not subject to clearing or mowing that lay adjacent to the stream banks. These corridors were delineated using 1:24,000-scale orthophotography and then located with on-site latitude/longitude readings from a Garmin-76 Geographic Positioning System (GPS) calibrated to a permanent survey marker in Kingston, RI, for an accuracy of 1–3 m. All sites were located between 41°33′ and 41°42′ north latitude, and 71°08′ and 71°43′ west longitude.

Assessing Riparian Vegetation for Habitat Condition

We established metrics for riparian habitat at two spatial scales: subwatershed and stream reach. Metrics at the subwatershed scale, derived from a Geographic Information System (GIS), were used for attributes that extended beyond the immediate riparian corridor adjacent to the stream reach. These included percent RLU, percent impervious surface (IS), percent wetland, percent forest, percent forest plus wetland, percent canopy, edge-to-area ratio, and size of the intact riparian area. To determine percent canopy, edge-to-area ratio, and intact riparian area, we used a GIS and

Table 2. Definitions of land use categories developed from 1995 aerial photography (1:24,000 scale)

Category	Definition
Residential	Low (>2 acre), medium (1/8 acre to 2 acre), and high (<1/8 acre) density lots.
Impervious surface	Calculated from the fractions of commercial/industrial, infrastructure, and residential land uses that are impervious (e.g., roofs, parking lots, etc.).
Commercial/Industrial	Sale of products and services, manufacturing, design, assembly, and mixed uses.
Infrastructure	Roads (>200 feet), airports, railroads, water and sewage treatment, waste disposal (landfills, junkyards), power lines (>100 feet width), other transportation facilities, institutions (schools, hospitals, churches).
Agriculture	Pasture, cropland, orchards, groves, nurseries, cranberry bogs, confined feeding operations, and idle agriculture (abandoned fields and orchards).
Forest	Deciduous, evergreen, mixed forest, brushland (shrub and brush areas, reforestation).
Wetland	Emergent wetland (marsh/wet meadow, emergent fen or bog), scrub-shrub wetland (shrub swamp, shrub fen or bog), forested wetland (coniferous, deciduous, dead).
Open Area	Vacant land, cemeteries, beaches (fresh and salt), sandy areas (not beaches), rock outcrops, mines, quarries, gravel pits, transitional areas, and mixed barren areas.
Water	Freshwater (ponds, lakes, streams).

Table 3. Land uses for site subwatersheds along a gradient of residential land use (RLU).

Survey sites	Wood River (WR)	Adamsville Brook (AB)	Donovan Brook (DB)	Annaquatucket River (AR)	Buckeye Brook (BB)	Gorton Brook (GB)	Tuscatucket Brook (TB)	Passeonkquis Brook (PB)
Anthropogenic land uses[b]								
Residential %	4	12	17	24	29	38	53	59
Impervious surface %[a]	1	3	3	8	43	27	47	30
Commercial/industrial %	0	0	0	2	7	8	17	6
Infrastructure %	1	2	1	4	37	14	23	6
Agriculture %	5	14	10	5	1	1	0	0
Recreational %	0	0	0	1	1	3	0	7
Natural land uses								
Forest %	79	52	25	33	7	19	3	5
Wetland %	10	17	44	18	9	6	2	6
Open area %	0	2	2	8	4	6	0	6
Water %	2	0	1	5	4	6	1	4
Riparian area (acres)	1238	1940	113	6	91	52	204	34

[a]Impervious surface is calculated from the fractions of commercial/industrial, infrastructure, and residential land uses that are impervious (e.g., roofs, parking lots, etc.).
[b]Generally, sites with low RLU are also low in other anthropogenic land uses.

orthophotos to create two oval-shaped perimeter lines with radii of 200 and 500 m, respectively, from either end of the 100 m stream reaches (Figure 2). This allowed us to examine the possible effects of fragmentation across subwatershed boundaries.

At the stream reach scale, metrics were calculated from measurements of vegetation within the riparian corridor, which was 100 m long by 40 m wide (Figure 3). These included percent tree cover, percent shrub cover, percent total vegetation cover, and percent invasive plant species. The zonation of tree canopy (overstory), shrubs/saplings (understory), and herbaceous plants (ground cover) was established by marking potential transect sites every 10 m along the stream reach and randomly selecting three for sampling (Roth and others 1996; James and Shugart Jr. 1970).

Each transect was 2 m wide and was sampled out to 20 m on either side of the stream bank to be within the 100-ft buffer of protection from development required by RI law (RIDEM 1998). The area of each transect was 40 m^2. We divided each transect into 1-m blocks and took five observations in each block, which gave us 100 observations per transect. Three transects were conducted along each stream bank for a total of six transects. We estimated the height of shrubs and trees with an inclinometer and measured tree diameter at breast

Figure 2. Orthophoto showing 200- and 500-m-radius perimeters around bird survey points used to assess forest fragmentation at each study site.

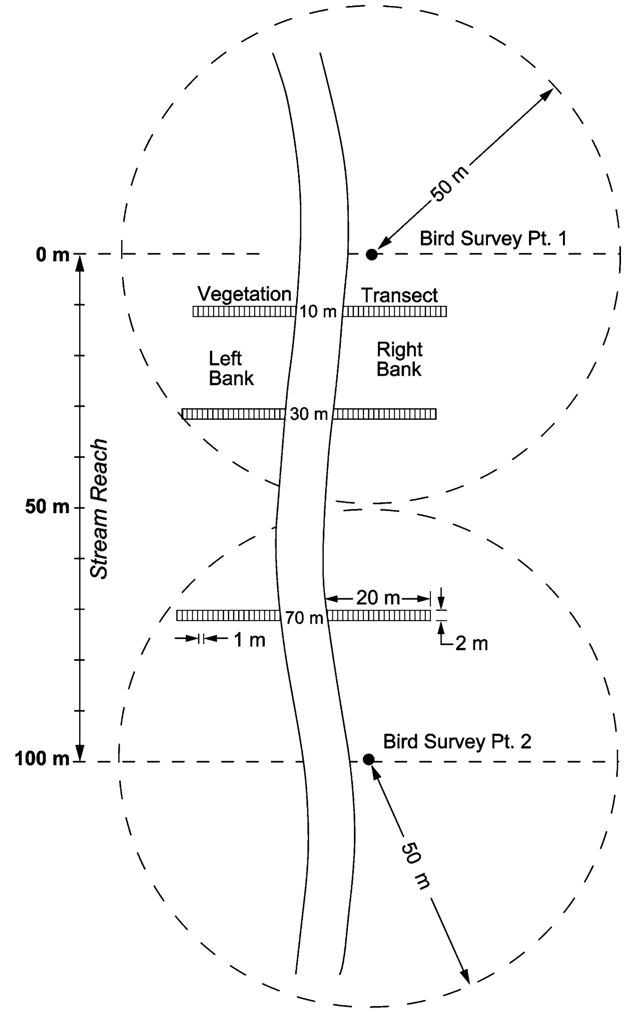

Figure 3. Riparian vegetation transects were located in the stream buffer within bird surveys.

height. The presence or absence of tree cover, plant species, and their associated layers (tree, shrub, or ground) were recorded for each observation. Vegetation was then characterized according to percent cover, species richness, and percent invasive species (daSilva 2003; Mehrhoff and others 2003). The percentage of total vegetation cover was calculated by summing totals of the three layers: percent tree cover, percent shrub cover, and percent ground cover. To better reflect the density of vegetation, we purposely included cover from overlapping layers of trees, bushes, and ground cover, which often resulted in a total cover more than 100%. Invasive species were calculated as the percent of total plant species and percent of the total vegetation cover.

Surveying Breeding Birds

Bird surveys followed the guidelines of the US Fish and Wildlife Service breeding-bird surveys (USFWS 1990; Stauffer 1980). All birds were counted by a single trained field observer who has more than 20 years of experience with survey technique. The sampling period was restricted to June in order to avoid counting migrating birds. Point-counts were conducted between sunrise and 4 hours later, with counts at each point lasting for 10 minutes. The sequence of stream sites was randomized with two sites surveyed per day. For each 100-m stream reach, birds were counted near the 0-m and 100-m marks about 5-m from the stream to avoid interference from the water noise (Figure 3). To avoid overlapping the two counts for each stream reach, only birds heard or seen within a 50 m radius were recorded. A Bushnell Yardage Pro® 500 was used to verify the point-count radius. Birds were counted on two different days for each stream, for a total of four point-counts at each site.

We used graphical and statistical methods to compare bird metrics with each of the vegetation and land-use metrics. Linear and nonlinear regressions were fit to bird metrics versus landscape metrics. Pearson correlation coefficients (R) and coefficients of variation (R^2) were computed for combinations of bird and landscape metrics (Zar 1999).

Bird Guilds and Metrics

Our approach combined various metrics and guilds that have been successfully used in previous studies to classify bird species. From our species lists, we developed bird guilds (Table A1) based on habitat preference, i.e., interior forest or forest edge (Dowd 1992); diet preference and foraging type (DeGraaf others 1985; DeGraaf and Yamasaki 2001; Bryce and others 2002); vegetation preference, i.e., shrub or canopy (DeGraaf others 1985; Degraaf and Yamasaki 2001); and wetland or nonwetland (upland) preference (DeGraaf and others 1985; Degraaf and Yamasaki 2001). Foraging type included birds that primarily use foliage-, bark-, or ground-gleaning to feed. The ground-gleaners included two subcategories: ground-gleaning granivores and ground-gleaning insectivores.

The metrics included the total number of individuals observed, the total number of species (richness), and the numbers of species that are tolerant or intolerant to human activities (Dowd 1992; Bryce and others 2002). Each stream site had four bird surveys: day 1, 0 m and 100 m and day 2, 0 m and 100 m. During the surveys, the number of each bird species was tabulated by quadrant on a circular plot. The number of each species at 0 m and 100 m was then summed for that day for each stream site. The same procedure was followed for the second day of surveys. To avoid overcounting when the data were combined from the two survey dates, we used the larger number of each species to represent nesting birds rather than averaging.

Results

Residential Land Use

At our sites, the largest percentages of anthropogenic land uses were (from largest to smallest) residential, commercial/industrial, infrastructure, and agriculture; the largest percentages of natural land uses, respectively, included forest, wetland, open area, water, and riparian area (Table 3). The category of IS, generally dominated by commercial/industrial land uses, also includes small effects of residential and infrastructure. Percentages of RLU and of IS were highly correlated with each other ($p = 0.017$) and with other anthropogenic land uses (Figure 4).

Riparian Vegetation

Dominant tree, shrub, and ground cover species for sites with low, medium, and high RLU are summarized in Table 4. The percentage of vegetation cover was often well over 100% because of the many layers at each zone (e.g., over- and understory trees in the tree zone, and saplings and bushes in the shrub zone). Rather than representing the extent by 100%, we included all layers to illustrate the density and complexity of vegetation available for nesting and foraging breeding birds.

As residential development increased, the number of plant species and extent of riparian vegetation (cover) decreased significantly ($p = 0.04$ and $p = 0.06$, respectively) at all layers (tree, shrub, and ground), but the percent invasive plant species and associated cover increased significantly ($p < 0.05$ for each) (Table 4).

At all sites, edge-to-area ratios were positively correlated with RLU, and percent canopy was negatively correlated.

Bird Guilds

Pearson correlations provide an overview of relationships of bird guilds with riparian vegetation (habitat) (Table 5). Critical data ranges (listed below coefficients) show the percentage or area of vegetated habitat associated with changes in bird species. For example, the number of tolerant bird species was positively correlated with percent RLU (0.738) at a range of 4–12% RLU.

Residential land use and IS were significantly negatively correlated ($p < 0.05$) with several bird guilds (number of intolerant species, number of forest species, and diet: number of insectivorous species). We saw a slightly better correlation between tolerant and intolerant bird species with RLU than with IS (Table 5). Shifts from intolerant to tolerant bird guilds occurred at 12% RLU and 3% IS. Nonlinear regressions of RLU versus the number of tolerant ($p = 0.006$) and intolerant ($p = 0.00009$) bird species and IS versus the number of tolerant ($p = 0.0075$) and intolerant ($p = 0.00014$) bird species are shown in Figure 5A and B.

The number of tolerant bird species was positively correlated with several other attributes of RLU (% IS, edge:area ratio, and percent invasive plant species) and negatively correlated with riparian vegetation attributes associated with forested areas (percent forest, percent wetland, percent canopy, percent tree cover, percent shrub cover, percent total vegetation cover, and riparian zone area) (Table 5).

Bird Habitat Guilds

The number of bird species classified as forest-interior (Table A1) decreased dramatically (to zero) when RLU reached 24%, whereas the number of species of forest-edge birds peaked at the same point and then leveled off (Figure 6A and B). A piecewise linear regression model resulted in an estimated join point for % RLU of 0.25 ($p = 0.0039$; CI of 0.17–0.34).

The number of bird species preferring shrubs or wetland habitat remained relatively constant with changes in RLU or IS. However, they did increase with

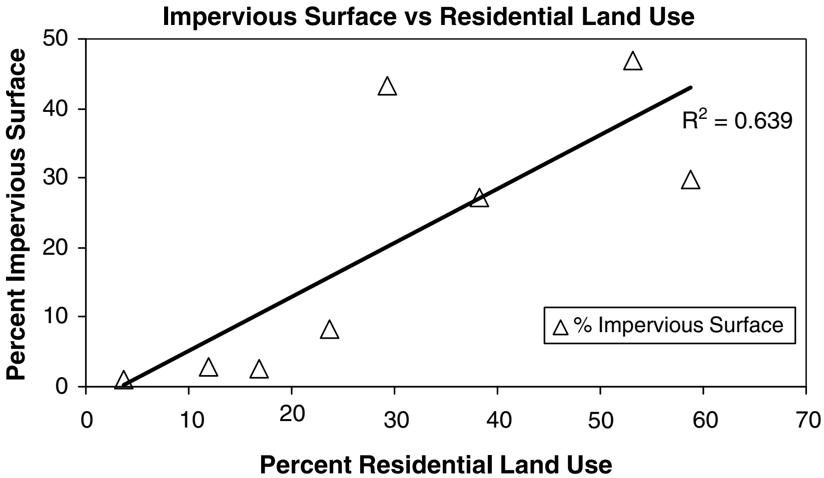

Figure 4. Linear regression of residential land use versus impervious surface ($p = 0.017$).

increasing wetland and with decreasing riparian area. Wetland species decreased significantly with decreasing percent forest and with decreasing canopy cover in both the 200 m and 500 m buffers (Table 5).

Bird Foraging Guilds

Of the foraging types, ground-gleaning birds were the most closely correlated with RLU. They increased significantly with increased edge and invasive vegetation, both of which increased with RLU (Table 5); they decreased significantly with increasing tree cover, canopy, and vegetative cover**.** Consequently, the heavily forested low-RLU sites (WR, AB, DB) had significantly fewer ground-gleaners.

The ground-gleaning foraging type included two subcategories (Table A1): ground-gleaning granivores (GG-GR), found only at developed sites (24–59% RLU) presumably because they need open areas to feed, and ground-gleaning insectivores (GG-INs), which have species-specific distributions and were found at all sites except PB, which had very little ground cover and more human activity than any other site.

Bark-gleaning (BGs) and foliage-gleaning (FGs) birds were found at all sites. Bark-gleaners decreased significantly with increasing edge:area ratio, but that may be due to only one site, AR, which had the greatest amount of edge within 200 m (Figure 5A). Foliage-gleaners showed no significant responses to changes in vegetation cover.

Bird Diet Guilds

Of the three bird guilds associated with diet-type, insectivores and granivores displayed the greatest differences with changes in vegetation and associated land use (Table 5). The omnivores, generally more adaptable to varied food types, were apparently less affected by changes in vegetation.

Insectivores (INs) decreased significantly with increased RLU and IS. More insectivore species were associated with interior forest habitat rather than with edge habitat. Insectivores decreased significantly with increasing edge (500 m) and increased with increasing forest and forest plus wetland (but did not change with increased wetland alone), indicating their preference for forested habitat.

The number of granivores decreased in habitat that had increased canopy within 200 m and 500 m, tree cover, shrub cover, and total vegetation cover; and increased as RLU and invasive vegetation increased (Table 4). Omnivores (OMs) increased significantly with edge (200 m) but were not correlated with any other metric (Table 5). They adapt to feeding in a variety of habitats and were more plentiful at all sites than birds with more-specific feeding preferences.

Subwatershed vs. Reach Scale and Bird Distribution

There were more correlations that were statistically significant between bird guilds and habitat indices at the subwatershed scale (e.g., acres of riparian vegetation, edge-to-area ratio, percent RLU, IS, wetland, forest, and canopy) than at the stream reach scale (e.g., percent tree, shrub, and vegetation cover) (Table 5). For example, percent canopy and percent forest were significantly correlated with various bird guilds more than any of the reach-scale indices.

Discussion

The positive correlation between RLU and IS at our sites allowed us to consider both as surrogate indicators of disturbance for the type of mixed land uses in our region. In the neighboring state of Connecticut, Arnold and Gibbons (1996) found that degradation of

Table 4. Summary of dominant (>10%) vegetation and extent of cover at riparian sites on a gradient of residential land use

Site and vegetation layers	% Residential land use[a]	Mean no species	% Vegetation cover[a]	% Invasive species (all layers)[a]	% Invasive cover (all layers)[a]	Average canopy height (m)	Average shrub Height (m)
WR:							
Trees		4.3	193			18.9	
Shrubs		10.3	113				2.1
Ground		21	117				
Total	4	35.6	416	0	0		
AB:							
Trees		7.3	223			21.3	
Shrubs		11.7	151				2.7
Ground		21.3	168				
Total	12	40.3	542	2	0.4		
DB:							
Trees		5.7	276			21.3	
Shrubs		8	146				3.4
Ground		16.7	138				
Total	17	30.4	560	2	0.7		
AR:							
Trees		4.7	87			16.5	
Shrubs		8.7	127				4.3
Ground		19.6	64				
Total	24	33	277	12	25		
BB:							
Trees		4.3	166			16.5	
Shrubs		12	148				3.4
Ground		12.7	63				
Total	29	29	376	9	9		
GB:							
Trees		4.3	95			24.4	
Shrubs		7.7	69				4
Ground		13	65				
Total	38	25	227	21	33		
TB:							
Trees		6.3	205			20.7	
Shrubs		10.7	129				4.3
Ground		14.7	79				
Total	53	31.7	412	9	13		
PB:							
Trees		2	27			21.3	
Shrubs		2	5				ND
Ground		4	15				
Total	59	8	53	31	31		

ND = no data.
[a]As development increased, total vegetation decreased significantly ($p = 0.06$), while the number of invasive plant species increased ($p = 0.04$).

stream-water quality first occurred at 10% imperviousness. In a review of studies conducted in many geographic regions, Schueler (1994) found that stream degradation occurred quite consistently at 10–20% imperviousness.

Pearson coefficients for our sites revealed significant changes in bird species composition within the ranges of 3–8% IS and 4–12% RLU (Table 5). We found that the guilds showing the most promise as indicators of human activity were tolerant and intolerant species. Contrary to our results, Bryce and others (2002) reported an overall decline in species richness with increasing disturbance. Their disturbed sites included some with intensive agriculture and others that were entirely urbanized commercial areas with channelized stream reaches. However, our sites were along a range of increasing suburban residential housing mixed with some commercial development (but with no channelized stream reaches) and were subject to more people feeding birds and possibly attracting the more tolerant species. Bryce and others (2002) also saw an increase in the number of tolerant

Table 5. Bird guild correlations with habitat indices showing positive or negative Pearson coefficients (at $p < 0.05$ and $p < 0.10$) and critical data ranges (% habitat associated with changes in bird species)

Habitat indices	% Residential land use	% Impervious surface	Riparian zone (acres)	Edge:area ratio (200 m/m^2)	Edge:area ratio (500 m/m^2)	% Forest	% Wetland	% Forest + wetland	% Canopy (200 m)	% Canopy (500 m)	% Tree cover	% Shrub cover	% Total vegetation cover	Invasive spp (% of total veg. cover)
Spatial scale	Subwatershed										Reach			
Bird guilds														
Habitat														
Tolerant	0.738[a]	0.603[b]	−0.750[a]	0.62[b]	0.756[a]	−0.744[a]	−0.383	−0.783[a]	−0.937[a]	−0.893[a]	−0.834[a]	−0.591	−0.839[a]	0.875[a]
	4%–12%[a]	3%–8%[b]	204–1237[a]	0.012–0.016[b]	0.016–0.018[a]	33–52%[a]		51%–69%[a]	48%–72%[a]	30%–68%[a]			412%–416%[a]	0.7%–9.4%[a]
Intolerant	−0.854[a]	−0.80[a]	0.724[a]	−0.340	−0.707[a]	0.935[a]	0.311	0.913[a]	0.766[a]	0.817[a]	0.538	0.492	0.626[b]	0.634[b]
	4%–12%[a]	3%–8%[a]	204–1237[a]	0.01–0.02	0.016–0.018[a]	19%–25%[a]		24%–51%[a]	48%–72%[a]	30%–68%[a]			412%–542%[b]	0.7%–9.4%[b]
Forest	−0.810[a]	−0.768[a]	0.785[a]	−0.614	−0.845[a]	0.877[a]	0.397	0.900[a]	0.938[a]	0.985[a]	0.616	0.349	0.631	−0.785[a]
	4%–12%[a]	3%–8%[a]	204–1237[a]	0.01–0.02	0.016–0.018[a]	33–52%[a]		51%–69%[a]	48%–72%[a]	30%–68%[a]			412%–416%	0.7%–9.4%[a]
Edge	0.605	0.491	−0.702[b]	0.767[a]	0.767[a]	−0.596	−0.402	−0.668[b]	−0.956[a]	−0.912[a]	−0.797[a]	−0.406	−0.741[a]	0.887[a]
	17%–24%		204–1237[b]	0.01–0.03[a]	0.018–0.025[a]			51%–69%[b]		30%–68%[a]			412%–416%[a]	0.7%–9.4%[a]
Wetland	0.491	0.392	−0.585	0.649[b]	0.626[b]	−0.751[a]	0.102	−0.584	−0.784[a]	−0.751[a]	−0.309	−0.010	−0.252	0.537
			204–1237	0.006–0.016[b]										
Upland	−0.430	−0.548	0.501	−0.188	−0.392	0.805[a]	−0.252	0.566	0.404	0.466	−0.244	−0.292	−0.188	−0.024
						52%–79%[a]								
Shrub	−0.204	−0.087	−0.538	0.522	0.072	−0.009	0.213	0.083	−0.450	−0.159	−0.245	0.107	−0.195	0.155
							6%–9%							
Canopy	−0.177	−0.476	0.708[a]	−0.089	−0.132	0.462	−0.033	0.372	0.394	0.285	0.059	−0.041	0.154	−0.086
			204–1237[a]											
Foraging														
Foliage gleaning	−0.049	−0.062	−0.24	0.144	0.017	0.197	−0.371	0.008	−0.268	−0.195	−0.603	−0.399	−0.546	0.58
Bark gleaning	0.239	0.419	0.333	−0.762[a]	−0.219	−0.057	−0.538	−0.275	0.37	0.126	0.064	−0.257	−0.046	−0.113
Ground gleaning	0.428	0.288	−0.512	0.852[a]	0.669[b]	−0.346	−0.406	−0.460	−0.887[a]	−0.761[a]	−0.845[a]	−0.388	−0.746[a]	0.777[a]
Diet				0.02–0.03[a]										
Granivorous	0.581	0.375	−0.554	0.369	0.511	−0.485	−0.398	−0.574	−0.697[b]	−0.666[b]	−0.890[a]	−0.777[a]	−0.896[a]	0.907[a]
Insectivorous	−0.862[a]	−0.788[a]	0.506	−0.048	−0.687[b]	0.772[a]	0.342	0.789[a]	0.331	0.58	0.107	0.341	0.285	−0.300
Omnivorous	0.103	−0.014	−0.377	0.804[a]	0.507	−0.090	−0.095	−0.115	−0.601	−0.520	−0.382	0.067	−0.255	0.489
				0.03–0.05[a]										

[a]Significant at <0.05; critical value = 0.707 (Zar 1999).
[b]Significant at <0.10; critical value = 0.621 (Zar 1999).

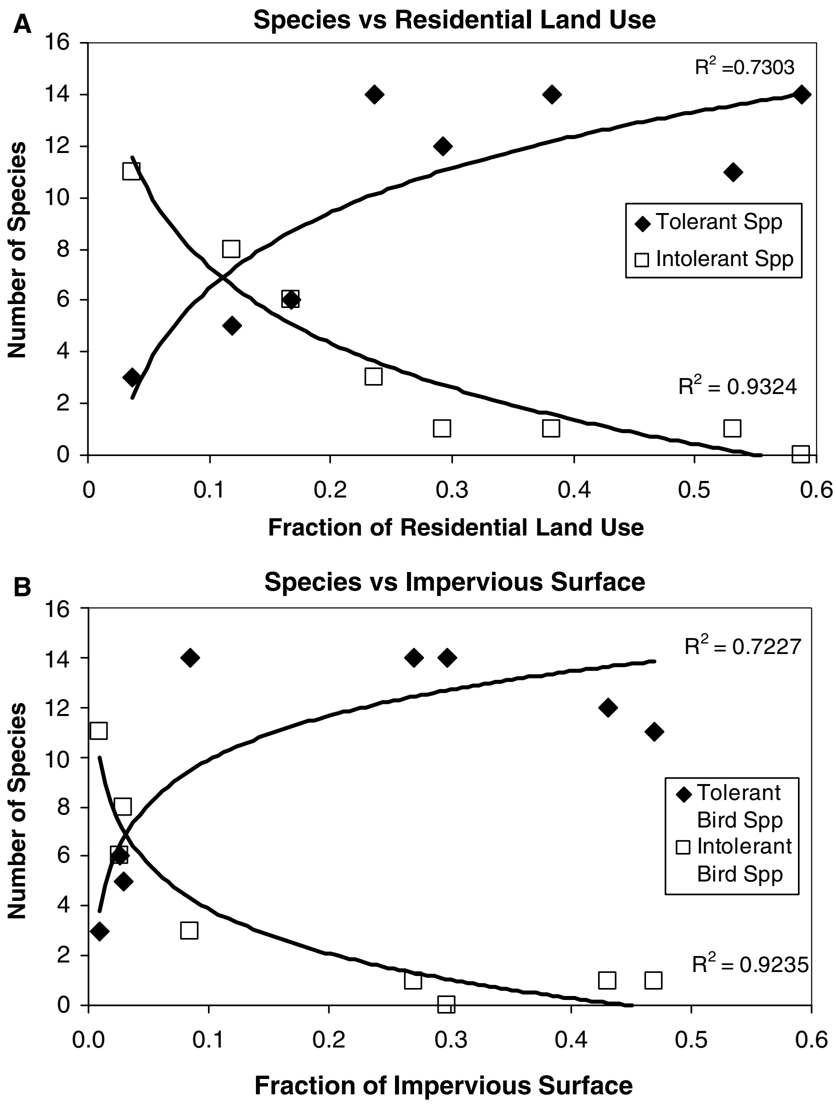

Figure 5. Shifts from intolerant to tolerant bird species with significant R^2 values (log regression) occurred with (**A**) increased residential land use and (**B**) increased impervious surface.

species with increasing disturbance. A California study found a shift in species similar to our results (Blair 1996). In that study, the composition of the bird community shifted from predominantly native species in the undisturbed area to invasive and exotic species in an urbanized area. Blair suggested that lower levels of development may increase the resources (vegetation and buildings) available to birds, increasing species diversity, whereas higher levels of development decrease the resources available to birds. Moderate levels of development also increase edge habitat up to a point, until even that vegetation is altered or eliminated.

These varying results from other studies emphasized to us the difficulty in determining the causes of species distribution because of the high correlation of many variables such as land use, vegetation, tolerance to human activity, habitat, and diet preference of individual bird species. Although our methods to obtain totals of individuals and species did not address differences in aural or visual detection due to vegetation density, the same observer used the same method at each site, all of which had similar habitats, so any bias would have been similar across all sites. Our main objective was to compare differences in bird guilds across a range of RLU rather than to obtain an accurate census.

Nevertheless, our eight sites revealed some possible threshold effects. The numerical dominance of tolerant versus intolerant species appeared to switch at 3% IS and at 12% RLU (Figure 5A and B). This indicates that even though the number of species remains the

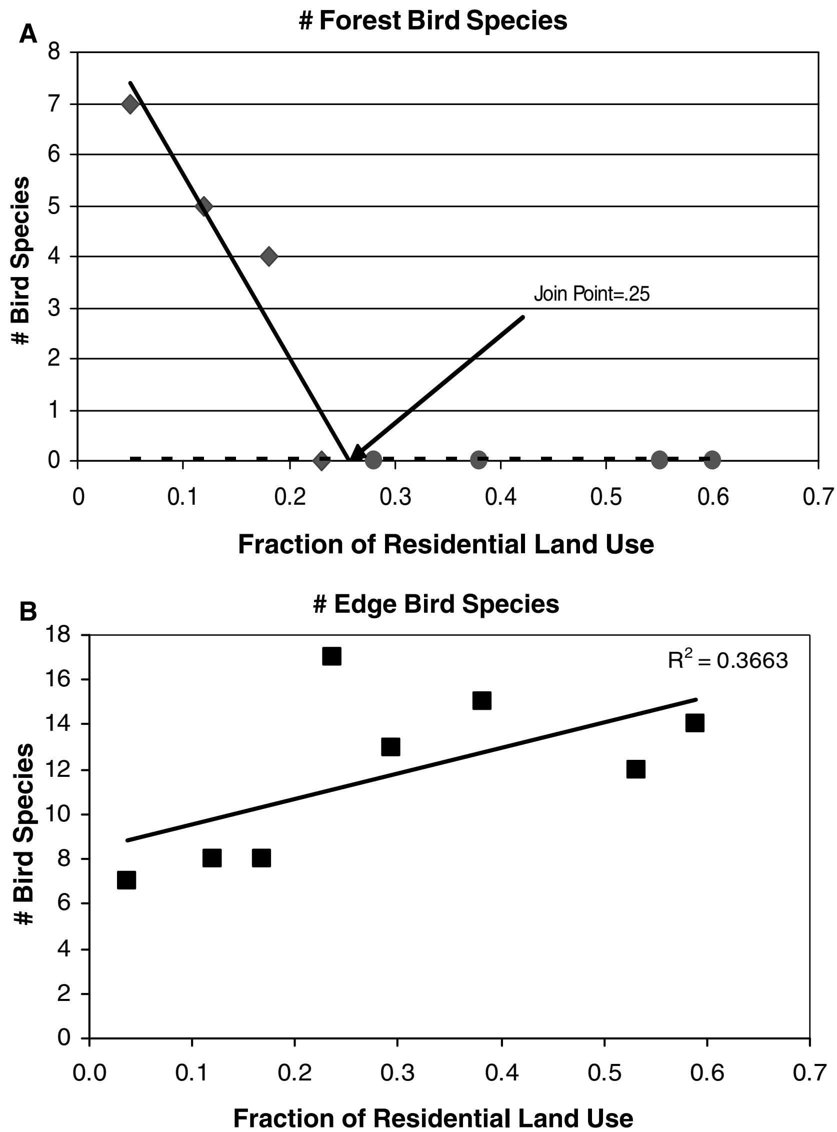

Figure 6. Forest birds decreased precipitously (**A**) as edge bird guilds gradually increased (**B**) with increasing residential land use. Piecewise linear regression shows an estimated join point for percent RLU of 0.25.

same, the species composition may change in response to land use. Table A2 lists the bird species counted at our sites according to tolerance of human activity. Intolerant species were found almost exclusively at the sites with low RLU and IS, whereas tolerant species were at the medium and high RLU sites.

O'Connell and others (1998), who also used guilds based on habitat use, found similar thresholds of vegetation and land-cover change where shifts in ecological integrity occurred. At their 79-ha scale (about the size of our TB site's riparian area), they found that 87% forest cover was required to achieve good-to-excellent ecological condition, and when urban/residential cover exceeded 29%, the condition was poor.

Invasive Vegetation

Our results show that invasive vegetation increased with increasing development at our study sites (IPANE 2004). Invasive plants were absent from low RLU sites, but increasingly abundant at medium and high RLU sites. The suitability of invasive vegetation as habitat, its food quality, and structural effects for birds is unclear. Even though the invasive plant species that produce fruit and berries are potential food sources for birds, the quality of that food is not well documented. Some New England studies have indicated that berries from certain species lack the fatty acids required to sustain migrating birds and that the food quality of native and invasive species is quite variable (Pierce 2003; Barton

Table A1. List of bird species, diet, and guilds

Common name	Scientific name	Food summary[a]	Habitat[b]	Tolerance[b,c]	Diet[a,c]	Foraging type[c]	Shrub/ canopy[a,c]	Wetland / nonwetland[a]
Acadian Flycatcher	*Empidonax virescens*	Insects, berries	F	I	IN	ND	C	W
American Crow	*Corvus brachyrhynchos*	Grains, seeds, fruits, nuts, frogs, mammals, carrion, insects, eggs, nestlings	E	U	OM	GG	C	N
American Goldfinch	*Carduelis tristis*	Grains, seeds, berries	E	T	GR	FG	S	W
American Redstart	*Setophaga ruticilla*	Insects, fruits	E	I	IN	ND	C	N
American Robin	*Turdus migratorius*	Fruit, worms, insects	E	U	OM	GG	C	N
Black-capped Chickadee	*Parus atricapillus*	Insects, seeds, fruits	E	G	IN	FG	S	N
Black-throated Green Warbler	*Dendroica virens*	Insects, worms, berries	F	I	IN	FG	C	N
Blue Jay	*Cyanocitta cristata*	Seeds, fruits, mast, insects, nestlings, mice, nuts	E	T	OM	GG	C	N
Carolina Wren	*Thryothorus ludovicianus*	Insects, fruit, ground litter	E	T	IN	BG	S	W
Chipping Sparrow	*Spizella passerina*	Insects, seeds	E	I	OM	GG	ND	N
Common Grackle	*Quicalus quiscula*	Insects, fruits, mast, grains, fish, amphibians, eggs, nestlings	E	T	OM	GG	ND	W
Common Yellowthroat	*Geothlypis trichas*	Insects, worms	E	T	IN	FG	S	W
Downy Woodpecker	*Picoides pubescens*	Insects	E	U	IN	BG	C	N
European Starling	*Sturnus vulgaris*	Insects, seeds, fruits, grains	E	T	OM	GG	C	W
Gray Catbird	*Dumetella carolinensis*	Fruit, insects in leaf litter	E	T	OM	FG	S	W
Great Crested Flycatcher	*Myiarchus crinitus*	Flying insects, insect larvae, fruit	E	I	IN	BG	C	W
Hermit Thrush	*Catharus guttatus*	Insects, worms, snails, amphibians, reptiles, fruits	F	I	IN	BG	S	N
House Finch	*Carpodacus mexicanus*	Seeds, buds, fruits, insects	E	T	GR	GG	C	N
House Sparrow	*Passer domesticus*	Insects, veg, fruits, seeds, garbage	E	T	OM	GG	ND	N
House Wren	*Troglodytes aedon*	Insects	E	T	IN	GG	S	W
Mourning Dove	*Zenaida macroura*	Seeds, grain, snails	E	T	GR	GG	ND	N
Northern Cardinal	*Cardinalis cardinalis*	Seeds, fruits, grains, insects, snails, slugs	E	T	OM	GG	S	W
Northern (Common) Flicker	*Colaptes auratus*	Insects, fruits, forages in lawns, pastures	E	U	IN	GG	C	W
Northern (Baltimore) Oriole	*Icterus galbula*	Insects, fruits, veg	E	T	OM	ND	C	N
Ovenbird	*Seiurus aurocapillus*	Insects, snails, worms, veg litter	F	I	IN	GG	C	N
Purple Finch	*Carpodacus purpureus*	Buds, seeds, blossoms, fruit, insects	E	I	OM	FG	S	W
Red-bellied Woodpecker	*Melanerpes carolinus*	Bug larvae and adults, fruits, nuts	E	T	IN	BG	C	W
Red-eyed Vireo	*Vireo olivaceus*	Insects	F	I	IN	ND	C	W
Red-winged Blackbird	*Agelaius phoeniceus*	Seeds, grain, insects	E	G	OM	GG	S	W
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	Insects, seeds, fruits	E	T	OM	ND	S	W
Ruby-throated Hummingbird	*Archilochus colubris*	Nectar, insects, sap	E	T	ND	ND	C	W
Scarlet Tanager	*Piranga olivacea*	Insects, fruits	F	ND	OM	ND	C	N
Solitary (Blue-headed) Vireo	*Vireo solitarius*	Insects, fruits	F	I	OM	ND	S	N
Song Sparrow	*Melospiza melodia*	Insects, fruits	E	U	OM	GG	S	W
Tufted Titmouse	*Parus bicolor*	Insects, snails, berries, seeds	E	T	OM	ND	C	W

Table A1. Continued.

Common name	Scientific name	Food summary[a]	Habitat[b]	Tolerance[b,c]	Diet[a,c]	Foraging type[c]	Shrub/ canopy[a,c]	Wetland / nonwetland[a]
Veery	*Catharus fuscescens*	Insects,fruit,seeds	F	I	OM	ND	S	W
Warbling Vireo	*Vireo gilvus*	Insects	E	I	IN	FG	C	W
White-breasted Nuthatch	*Sitta carolinensis*	Insects, seeds, fruits, mast (nuts on ground)	E	I	IN	BG	C	N
Wood Thrush	*Hylocichila mustelina*	Insects, fruits	F	I	OM	ND	C	W
Yellow Warbler	*Dendroica petechia*	Insects, worms	E	ND	IN	ND	S	W
Yellow-throated Vireo	*Vireo flavifrons*	Insects, moths, fruit, seeds	E	ND	OM	ND	C	W

[a]DeGraaf and others 1985; DeGraaf and Yamasaki 2001.

[b]Dowd 1992.

[c]Bryce and others 2002.

Habitat: F, Forest Interior; E, Forest Edge.

Tolerance: G, Generalist; I, Intolerant; T, Tolerant; U, Ubiquitous; ND, No Data.

Diet: GR, Granivore; IN, Insectivore; OM, Omnivore.

BG, Bark-Gleaner; FG, Foliage-Gleaner; GG, Ground-Gleaner; ND, No Data.

Shrub/Canopy: S, Shrub; C, Canopy.

Wetland/Nonwetland: W, Wetland; N, Nonwetland.

Table A2. List of bird species counted at survey sites along residential land use gradient, categorized by tolerant and intolerant bird guilds.

Survey site		WR	AB	DB	AR	BB	GB	TB	PB
Bird species counted	% Residential land use	4	12	17	24	29	38	53	59
	% Impervious surface	1	3	3	8	43	27	47	30
Intolerant species[a,b]									
Acadian Flycatcher	*Empidonax virescens*		■						
American Redstart	*Setophaga ruticilla*		■	■	■				
Black-throated Green Warbler	*Dendroica virens*	■							
Chipping Sparrow	*Spizella passerina*	■							
Great Crested Flycatcher	*Myiarchus crinitus*		■					■	
Hermit Thrush	*Catharus guttatus*	■							
Ovenbird	*Seiurus aurocapillus*	■	■	■					
Purple Finch	*Carpodacus purpureus*	■							
Red-eyed Vireo	*Vireo olivaceus*	■		■					
Scarlet Tanager	*Piranga olivacea*	■	■						
Solitary (Blue-headed) Vireo	*Vireo solitarius*	■							
Veery	*Catharus fuscescens*	■	■	■					
Warbling Vireo	*Vireo gilvus*				■		■		
White-breasted Nuthatch	*Sitta carolinensis*	■	■						
Wood Thrush	*Hylocichila mustelina*		■	■					
Yellow Warbler	*Dendroica petechia*			■	■	■			
Yellow-throated Vireo	*Vireo flavifrons*	■							
Total # Intolerant Species		11	8	6	3	1	1	1	0
Tolerant species[a,b]									
American Crow	*Corvus brachyrhynchos*				■				■
American Goldfinch	*Carduelis tristis*						■		
American Robin	*Turdus migratorius*	■	■		■	■	■	■	■
Black-capped Chickadee	*Parus atricapillus*					■			■
Blue Jay	*Cyanocitta cristata*			■	■			■	
Carolina Wren	*Thryothorus ludovicianus*			■		■	■	■	■
Common Grackle	*Quicalus quiscula*				■	■	■	■	■
Common Yellowthroat	*Geothlypis trichas*				■		■		■
Downy Woodpecker	*Picoides pubescens*						■		
European Starling	*Sturnus vulgaris*						■		■
Gray Catbird	*Dumetella carolinensis*	■	■	■	■	■	■	■	
House Finch	*Carpodacus mexicanus*								■
House Sparrow	*Passer domesticus*						■		
House Wren	*Troglodytes aedon*				■				
Mourning Dove	*Zenaida macroura*				■	■	■		■
Northern Cardinal	*Cardinalis cardinalis*	■	■	■	■	■	■	■	■
Northern Flicker	*Colaptes auratus*		■		■	■	■	■	
Northern (Baltimore) Oriole	*Icterus galbula*						■	■	
Red-bellied Woodpecker	*Melanerpes carolinus*					■			■
Red-winged Blackbird	*Agelaius phoeniceus*				■	■		■	
Rose-breasted Grosbeak	*Pheucticus ludovicianus*			■	■				
Ruby-throated Hummingbird	*Archilochus colubris*							■	■
Song Sparrow	*Melospiza melodia*				■	■			■
Tufted Titmouse	*Parus bicolor*		■	■	■	■	■	■	■
Total # Tolerant Species		3	5	6	14	12	14	11	14

Note: Black square indicates presence of species at site. For site abbreviation definitions, see Figure 1 legend.
[a]Dowd 1992.
[b]Bryce and others 2002.

2004). Effects on insectivorous birds reported by Tallamy (2004) indicated that insects are more attracted to native plants than to exotic plant species, so the volume of insects available as a food resource for migrating and breeding birds may decrease as exotics replace native species. More study is needed to understand the implications of invasive plants as a food source for breeding birds.

Indirect adverse effects on nesting have also been attributed to nonnative vegetation. Schmidt and Whelan (1999) found that habitat fragmentation and disturbance increased the prevalence of exotic plant species, which may be attractive for nesting, but result in higher predation of songbirds. The plants' structure allowed for lower nest height and, coupled with the absence of thorns, allowed predators to reach the nests more easily.

The structure of native vegetated habitat is complex, providing various resources such as food, protection, and nesting sites for different types of birds (Cody 1985). Native birds tend to be found in native, structurally complex habitats (Hennings and Edge 2003). As land becomes increasingly developed, the plant structure becomes simpler and fragmented areas with more edges become the norm.

The riparian vegetation at our sites had decreased density and complexity available for nesting birds as RLU increased. Forest fragmentation, measured by edge-to-area ratios and percent canopy, increased significantly with RLU and was a valuable indicator of forest bird populations and easily obtainable by using a GIS.

Other studies have shown a reduced bird density when exotic plant species dominate the habitat (Anderson and others 1977) and higher densities of native birds in urban neighborhoods landscaped with mostly native vegetation (Mills and others 1989). Bird density at our sites did not change as RLU increased, but there was a clear increase in the number of tolerant species at the urbanized sites (Figure 5A and B).

Habitat and Diet Guilds

A number of studies have shown that bird habitat guilds reflect changes in residential development. Brooks and others (1991) found that resident and neotropical-migrant breeders that had specific habitat requirements decreased in disturbed habitats, whereas bird species that preferred edges (habitat generalists) were found in greater abundance in disturbed watersheds. Friesen and others (1995) found that neotropical migrants consistently increased in number and abundance as forest size increased, and decreased in diversity and abundance as adjacent housing development increased, regardless of forest size.

In a California study, Rottenborn (1999) found no clear patterns of distribution of ground-foraging or seed-eating species relative to urbanization, but did report a decrease in the number of species that glean insects from foliage or bark with increased urbanization and postulated that it might be due to more abundant exotic vegetation with lower insect densities. In our study, only one site, AR, showed decreased numbers of bark-gleaners, and there was a clear increase in the number of ground-gleaners with increasing RLU. The conflicting results from these studies emphasize the importance of conducting similar studies in different geographic regions to understand how vegetation and bird species may differ in their response to land use and various landscaping practices.

Spatial Scale

The issue of scale has been addressed in a number of studies. Hennings and Edge (2003) found that it was critical to assess multiple scales in urban habitat because the strongest relationship between native bird communities and habitat occurred within 150 m of a stream and that fine-scale changes (50 m) can affect native bird community patterns. However, at a larger scale, abundant urban canopy cover is important to conserve native breeding birds because it increases their preferred structurally diverse habitat. At our sites, we found that subwatershed-scale metrics were better indicators of breeding birds than reach-scale metrics (Table 5). The methods associated with each scale contributed to our evaluation because methods used to collect reach-scale data required more on-the-ground time and effort than methods we applied to the subwatershed scale. Also, because our sites were all deciduous wetland riparian areas, and the structure of their vegetative layers was quite similar, it might have been more difficult to see differences among our sites at the reach scale.

Hansen and Urban (1992) expressed the need for caution when extrapolating community dynamics from one system to another. Communities from distinct geographic locations are likely to respond to their unique surrounding landscape, so the responses of a broad range of guilds and species should be examined. Our results were comparable to other studies in eastern urbanized landscapes and support the evidence that nearby land use affects riparian vegetation and its ability to support breeding birds (Brooks and others 1991; Hansen and Urban 1992; Small and Hunter 1988), smaller urban forests favor non-native plants and birds, and increased RLU and IS are associated with changes in species richness and diversity (Hennings and Edge 2003).

Because our subwatersheds were small with indistinct riparian corridors, we chose to survey the vegetation within a set buffer and measure the percent contiguous riparian canopy within 200 and 500 m of the sampling sites. We found that as the percent of riparian canopy increased, the number of intolerant-forest bird species increased, whereas edge and wetland species decreased (Table 5).

For determining the suitability of habitat for avian communities at various spatial scales, riparian-corridor width is an important metric. Fischer (2000) summarized research on recommended minimum widths of riparian corridors for birds. Corridor widths necessary to support a diverse bird community ranged from 175 m in Vermont (Spackman and Hughes 1995) to 500 m in South Carolina (Kilgo and others 1998).

Some suggestions by Rottenborn (1999) include creating broad buffers of undeveloped land between developed areas and riparian areas, rather than building right up to the riparian buffer. This would also discourage human disturbance to the riparian habitat. He also recommended linking fragments of riparian habitat whenever possible to increase the total riparian area, a variable that enhanced interior forest species in our study. Any increases in tree canopy in residential areas would help to increase structural diversity, but especially near existing riparian habitat. Hennings and Edge (2003) also suggest decreasing street density within a 100-m radius of riparian zones. Several authors recommend using native shrubs and trees in landscaping to enhance resources such as food, nesting structure, and protection from predators and weather (Rottenborn 1999; Schmidt and Whelan 1999; Hennings and Edge 2003; Pierce 2003; Barton 2004; Tallamy 2004).

Conclusions

Residential land use and IS correlated with bird distribution better than any other land use. As they increased, we saw altered habitat such as greater edge-to-area ratio (fragmentation) and more invasive plant species, but less riparian area, vegetation cover, and canopy cover.

By categorizing the observed bird species into functional guilds, we were able to determine which guilds were more closely correlated with various levels of RLU. Although several of the habitat guilds correlated with riparian vegetation (e.g., edge, forest, and wetland species), the only responsive foraging guild was ground-gleaners, and the only diet guilds that showed distinct differences were granivores and insectivores, which showed changes at both the reach and subwatershed scales. They decreased significantly with increasing tree cover and total vegetative cover (reach scale) and canopy (subwatershed scale), and increased with increasing edge (subwatershed scale).

Tolerance to human disturbance proved to be a valuable metric to reveal the effects of RLU and IS on biodiversity (Table A2). The relative number of tolerant and intolerant bird species switched at 12% RLU, and at 3% IS. Bird-habitat guilds revealed a complex interaction between birds and the structure of surrounding vegetation. As expected, all forest-interior bird species were intolerant to developed areas, whereas most forest-edge bird species were tolerant.

Among diet guilds, insectivores and granivores correlated best with RLU. Insectivorous species were associated with interior forest habitat and granivores were associated with open habitat.

We assessed the riparian vegetation at both the subwatershed and reach scales, with methods appropriate to each, to determine which would be more predictive of breeding-bird suitability and which would be easier, more useful and economical for managers to use. Subwatershed-level metrics (land uses, edge-to-area ratio, percent canopy, and riparian area) were good indicators of the habitat suitability for birds and fairly easy to obtain. The vegetation metrics at the reach scale were difficult and time-consuming to obtain and, with the exception of total vegetative cover, were not as useful as the broader scale metrics. Bird guilds were generally better correlated with metrics at the subwatershed rather than the reach scale. Both RLU and IS were valuable subwatershed-scale indicators.

Environmental managers are encouraged to use the results from the many studies on the effects of development to plan new development with conservation of native riparian vegetation and breeding birds in mind. Much of the data needed for planning development and conserving important riparian areas are now readily available. A GIS can provide valuable landscape/land use data at the watershed scale, and response guilds that are linked with habitat can serve as screening tools to determine the level of disturbance in watersheds to distinguish which should be targeted for habitat restoration or protection (Croonquist and Brooks 1991). Riparian habitats are critical in their support of endangered and threatened wildlife and plants (Brooks and Croonquist 1990), and their conservation is essential to ensure biologically diverse ecosystems.

This study was conducted to assess the relationship of land use with the condition of riparian vegetation regarding its use by breeding birds. Our results demonstrate that species richness, tolerance, and habitat preference of breeding birds were correlated with riparian vegetated habitat and RLU, revealing patterns of breeding bird distribution. These results can be applied by environmental managers to assess watersheds comprehensively with methods that offer consistency throughout the United States, and to plan new development that emphasizes conservation of native riparian vegetation and breeding birds.

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